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BEHAVIOR OF AVIATION ENGINES AT DIFFERENT AIR DENSITIES.

By

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BEHAVIOR OF AVIATION ENGINES AT DIFFERENT AIR DENSITIES.*

By

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At a meeting of the Scientific Society for Aviation, March 12, 1920, the question was brought up, as to what influence the low temperatures and air densities at high altitudes exert on engine power. The writer expressed the view that it would be affected only at very low temperatures, and this on account of the effect on the carburetion. Mr. Koenig maintained that the engine would fill even better with a falling temperature and constant density of the surrounding air since the weight of the cylinder charge would be less affected by the preliminary heating of the air. The latter view, however, is erroneous for the following reasons:

Aside from humidity, the density of the air depends on two factors: air pressure and temperature. The air density is represented by the equation $\gamma = \frac{P}{RT}$. For example, if γ is 0.6 kg/cu.m., it may result either from a high temperature and a high pressure or from a low temperature and a low pressure.

Let $t = 30^\circ C$ in one case and -30° in the other. The pressures for $\gamma = 0.6$ are then found:

1. For $t = +30^\circ$

$$P = \gamma R T = 0.6 \quad 29.26 \; (273 + 30) = 5320 \text{ kg/sq.m.}$$

2. For $t = -30^\circ$

$$P = \gamma R T = 0.6 \quad 29.26 \; (273 - 30) = 4260 \text{ kg/sq.m.}$$

* From "Zeitschrift für Flugtechnik und Motorluftschiffahrt," March 31, 1920.

If the temperature of the air entering the carburetor is raised 30° by the preliminary heating, we then obtain for its density:

$$1. \quad \gamma = \frac{P}{R\ T} = \frac{5320}{39.26\ (273 + 30 + 30)} = 0.546 \text{ kg/cu.m.}$$

$$3. \quad \gamma = \frac{P}{R\ T} \quad \frac{4620}{39.26\ (273 - 30 + 30)} = 0.533 \text{ kg/cu.m.}$$

The above calculations demonstrate that, with the same density and lower temperature, like heating exerts a greater reducing influence on the weight of a cylinder charge than at a higher temperature.

Really this result was to be anticipated, since like heating is relatively greater at low than at high temperatures. In reality, however, the heating is about the same. At very low outside temperatures, the crank case is naturally colder than at higher outside temperatures, but still with a difference of 60° in the outside temperature, the difference in the temperature of the crank case walls will be somewhat less than 60°. For example, let us assume a difference of 20° in the temperature of the crank case walls. With an outside temperature of +30°, the temperature of the crank case walls is about 60° and with an outside temperature of -30° and the same loading of the engine, 60 - 20 = 40°. In the preliminary heating of the air, we accordingly have, at +30° outside temperature, a temperature rise of 60 - 30 = 30°, and at -30° outside temperature we have a rise of 40 - (-30) = 70° The amount of the preliminary heating at a lower outside temperature would accordingly be greater, rather than smaller. The weight of a cylinder charge is therefore smaller at low temperatures than at high temperatures, with the same density of the outside air. The difference however is so slight as to be practically negligible.

The carburetion is affected by great differences in temperature, but even here any considerable influence is only exerted by very low temperatures, as shown by the following consideration.

Even at -18° the air is saturated with the quantity of gasoline required for good combustion. At -15° its degree of saturation is 85%, when all the fuel possible has been evaporated (Fig. 1). With the cooling of the gasoline of about 30° from evaporation, a temperature of $+15^{\circ}$ of the inflowing air is sufficient for complete carburetion. Therefore an average preliminary heating of the air of 30 to 35° will produce complete carburetion with an outside temperature of -15 to -20°.

At still lower temperatures, the carburetion will be no longer complete, but the fuel will be partially held in the mixture in the form of a mist. According to the nature of this mist, whether coarse or fine, there is more or less danger of its separation in passing from the carburetor to the cylinders. High air velocity at the spraying nozzle and in the intake pipes facilitate the formation and retention of a fine mist. The higher these velocities are, the smaller is the danger of separation and consequent effect on the combustion. In aviation engines, the air and gas velocities are relatively high and the danger of separation very small, so that only very low temperatures can have any considerable influence on the carburetion. Some improvement can be effected however by heating the intake pipes. With carefully arranged gas pipes, however, such heating of the pipes may be omitted without detriment to the functioning of the engine.

It may be safely assumed that, down to outside temperatures of -30°, the proper functioning of the carburetor will not be seriously affected. Up to altitudes of about 7000 meters, no change in the carburetion detrimental to the combustion may be expected from low temperatures and consequent separation of the mixture of fuel and air. The efficiency of the engine may be affected however by exceptionally low temperatures. In altitude record flights precautionary measures must accordingly be adopted for the carburetor, such as the preliminary heating of the inflowing air or the supplementary heating of the mixture, possibly even by the introduction of electric heaters into the gas circulation. Such measures (on account of the diminution in the weight of a cylinder charge) will naturally reduce the engine efficiency, which fact may however be disregarded, when it becomes a question of enabling the engine to function at all at exceptionally low temperatures.

Down to air temperatures of about -50° and with the employment of high altitude carburetors which automatically equalize the heat of the mixture with changing air density, the indicated engine power N_i must remain exactly proportional to the air density. The effective engine power N_e, on the contrary, will decrease more rapidly.

The loss in engine power (or friction horsepower), $N_v = N_i - N_e$, is the result, on the one hand, of the friction of the driving gear and, on the other hand, of the friction in the cam gear, the ignition, the water, oil and fuel pump, compressed air pump and any other auxiliary apparatus. The first component depends on the load, hence on the indicated engine power and the air density, and is therefore relative. The other component is almost independent of the load and consequently remains uniform. The constant friction component in good aviation engines may be assumed to absorb about 10% of the indicated engine power, while the component proportional to the air density absorbs about 5% at maximum engine power.

The engine power in relation to the air density γ or the relative air density μ may be represented after a fashion on the basis of the engine power at 15°C and 760 mm. Hg. (Fig. 2).

Deviations from the curves thus obtained may of course occur, but they are of no practical importance. Greater deviations occur when carburetors without altitude regulation are used and these deviations may be either upward or downward.

The effective engine power for higher air densities during a part of the curve will lie above the theoretical power for engines with high altitude carburetors, if the engine has been adjusted on the ground for running most economically, that is, with a very "poor" combustible mixture. The mixture will then become richer as the air density diminishes and the engine power will continue to rise above its theoretical value until the most favorable ratio of fuel and air is reched. As the air density still further diminishes, the fuel mixture becomes too rich and the engine power decreases until it falls below the theoretical power. If the carburetor has been adjusted to give the highest power on the ground, then any increase in the fuel ratio will diminish the engine power with reference to the theoretically possible, so that the power curves will fall below the theoretical from the start.

While the altitude power curve of an engine provided with an automatic high altitude carburetor may be drawn with sufficient accuracy, as explained above, for engines with ordinary carburetors the deviations from the theoretically possible powers can only be roughly estimated. The deviations could be more accurately determined, if the engine were driven on the ground with the fuel mixtures obtaining for the different air densities and the engine powers were determined independently of the heat values of the mixtures. In this manner, the real engine powers could be more closely determined. The curves found could be verified by subsequent counting of the r.p.m. in flight, with simultaneous determination of the air densities. Hereby the airplane would have to be driven at exactly the same speed at all the different air densities, in order to determine their influence on the revolution speed.

Such a method for determining the altitude engine powers would always be conceivable even though somewhat roundabout.

The vacuum chamber, free air tests and dynamometer hub naturally give more accurate results and are to be preferred.

Translated by the National Advisory Committee for Aeronautics.

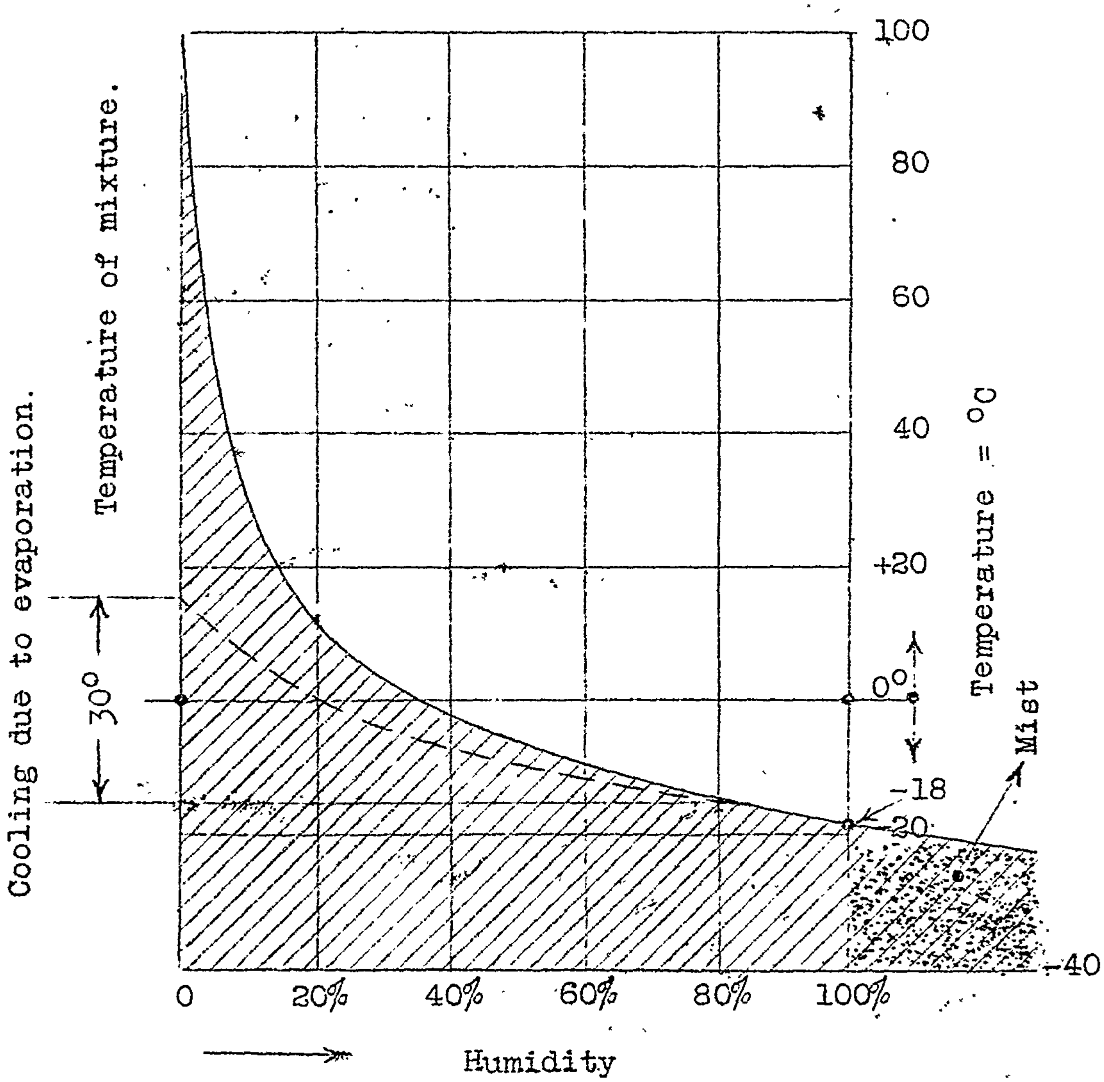
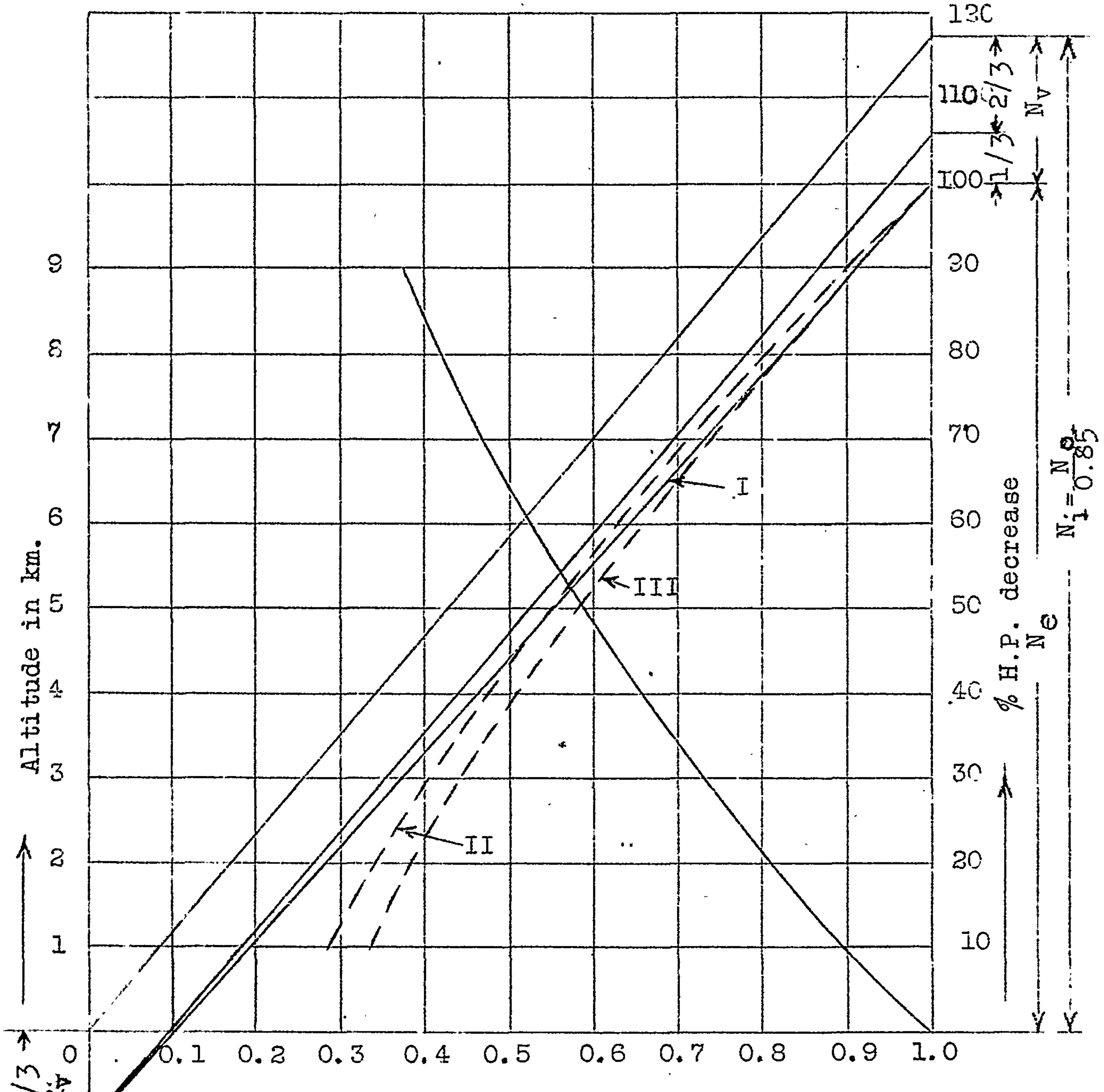

Cooling due to evaporation.
Temperature of mixture.
30°
100
80
60
40
+20
0°
-18
-20
-40
Temperature = °C
Mist
0
20%
40%
60%
80%
100%
Humidity

Fig. 1.



Altitude in km.
% H.P. decrease N_e
Humidity μ
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
110
120
I
II
III
2/3
1/3
N_v
$N_i = \frac{N_e}{0.85}$

Fig. 2.